TOXECON™ RETROFIT FOR MERCURY AND MULTI-POLLUTANT CONTROL

2006 SYMPOSIUM ON WESTERN FUELS

Authors:

***Steven Derenne**
We Energies
231 W. Michigan St.
Milwaukee, WI 53203

Robin Stewart
C. Jean Bustard
Sharon Sjostrom
Dave Muggli
Travis Starns
ADA-ES, Inc.
8100 SouthPark Way, Unit B
Littleton, CO 80120-4525

Ramsay Chang, Ph.D.
EPRI
3412 Hillview Avenue
Palo Alto, CA 94304-1395

Paul Sartorelli
Dick Johnson
We Energies
231 W. Michigan St.
Milwaukee, WI 53203

Ted McMahon
Fred Sudhoff
U.S. DOE/NETL
3610 Collins Ferry Road, P.O Box 880
Morgantown, WV 26507-0880

Ron Utter
Jeffrey Cummings
Cummins & Barnard, Inc.
5405 Data Court, Suite 100
Ann Arbor, MI 48108

ABSTRACT

The EPA published the Clean Air Mercury Rule (CAMR) on March 15, 2005, which included requirements for existing and new coal-fired power plants to limit the amount of mercury in their flue gas emissions. It is also highly desirable that coal utilization byproducts are beneficially used, thereby reducing waste products. TOXECON™ is an EPRI-patented process where sorbents for mercury and other air toxic emissions control are injected into a pulse-jet baghouse that is installed downstream of the existing particulate control device. The TOXECON™ configuration allows for separate treatment or disposal of the ash collected in the primary particulate control device.

We Energies and DOE, under a Clean Coal Power Initiative program, have been working together to design, install, evaluate and operate TOXECON™ as an integrated emissions control system for mercury and particulate matter from three 90-MW units at the Presque Isle Power Plant located in Marquette, Michigan. The project will also investigate the capabilities of TOXECON™ for SO_2 and NO_x control.

Demonstration of TOXECON™ at the Presque Isle plant began in January 2006. This paper will discuss engineering considerations in the design of this system and start-up activities. Results from the baseline and parametric testing will be presented in this paper, as well as unexpected balance-of-plant issues that arose and are currently being resolved.

INTRODUCTION

DOE Clean Coal Power Initiative

The Department of Energy's Clean Coal Power Initiative (CCPI) is an industry/government cost-shared partnership to implement clean coal technology under the National Energy Policy. The National Energy Policy investment in clean coal technology focuses on increasing the domestic energy supply, protecting the environment, ensuring a comprehensive energy delivery system, and enhancing national energy security. CCPI is an important platform for responding to these priorities. The CCPI was initiated in 2002 with a goal of accelerating commercial deployment of advanced technologies to ensure the United States has clean, reliable, and affordable electricity.

In January of 2003, the Presque Isle TOXECON™ project was selected as one of the first eight CCPI Round I projects. The DOE's National Energy Technology Laboratory (NETL) is managing the project. This five-year, $53 million project, of which the DOE is contributing $24.9 million, is the nation's first full-scale commercial deployment of the TOXECON™ process to control emissions of mercury and other air emissions.

Project Description

The primary goal of this project is to reduce mercury emissions from three 90-MW units that burn Powder River Basin coal at the We Energies Presque Isle Power Plant (PIPP). Additional goals are to reduce nitrogen oxide (NO_x), sulfur dioxide (SO_2), and particulate matter (PM) emissions, allow for reuse and sale of fly ash, demonstrate a reliable mercury continuous emission monitor (CEM) suitable for use in the power plant environment, and demonstrate a process to recover mercury captured in the sorbent. To achieve these goals, We Energies (the Participant) has designed, installed, and is operating a TOXECON™ system designed to clean the combined flue gases of Units 7, 8, and 9 at the Presque Isle Power Plant.

TOXECON™ is an EPRI-patented process (U.S. Patent 5,505,766) for removing pollutants from combustion flue gas by injecting sorbent in between an existing particulate collector and a fabric filter (baghouse) installed downstream of the existing collector for control of toxic species, including mercury, NO_X and SO_2. For this project, the flue gas emissions are controlled from the three units using a single baghouse. Mercury is controlled by injection of activated carbon or other novel sorbents, while NO_x and SO_2 will be controlled by injection of sodium-based or other novel sorbents. Addition of the TOXECON™ baghouse also provides enhanced particulate control. Sorbents are injected downstream of the existing particulate control device to allow for continued sale and reuse of captured fly ash that is uncontaminated by activated carbon or other sorbents.

The TOXECON™ configuration, shown in Figure 1, allows for separate treatment or disposal of the ash collected in an ESP (99% or greater) and the ash/sorbent collected in the TOXECON™ baghouse. At Presque Isle, the existing particulate collectors are hot-side electrostatic precipitators.

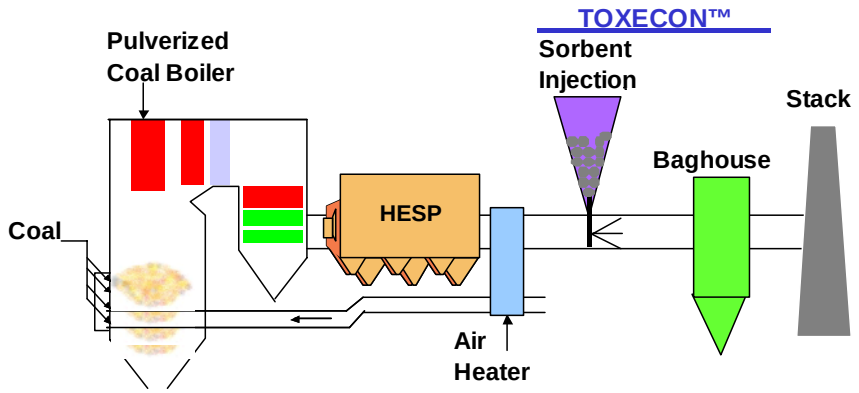

Figure 1. TOXECON™ Configuration.

The Powder River Basin subbituminous coal used is supplied by several mines in Wyoming and Montana (dependent on the price of the fuel) and shipped by rail to Superior, Wisconsin, where it is then loaded onto a lake boat for delivery to the PIPP. A typical coal analysis is presented in Table 1. Analysis of the coal sampled at Presque Isle in 2001 showed a mercury concentration of 0.046 µg/g. Typical flow rates and gas components in the flue gas exiting the hot-side ESPs (HESPs) of Units 7–9 are shown in Table 2.

Table 1. Compositional Analysis of PRB Coals Fired at PIPP Units 7, 8, and 9.

Characteristic	Typical Value
Higher Heating Value, Btu/lb	9,052
Analysis, percent by weight	
Moisture	25.85
Carbon	52.49
Hydrogen	3.65
Nitrogen	0.75
Sulfur	0.28
Ash	4.64
Oxygen	12.3
Chlorine	0.01

Table 2. Comparison of Flue Gas Composition Downstream of HESPs in Flues 7, 8, and 9 at the Presque Isle Power Plant.

Characteristic	Flue 7	Flue 8	Flue 9
Gas Volumetric Flow Rate, acfm	377,719	375,014	335,439
Average Gas Temperature, ºF	364.6	344.8	366.6
Flue Gas Moisture, % by volume	12.1	13.3	12.7
Average % CO_2 by volume, dry basis	12.8	13.0	13.0
Average % O_2 by volume, dry basis	6.2	6.0	6.0
Filterable PM, lb/hr	15.13	9.99	20.35
NO_x, lb/hr	407.8	410.5	406.8
SO_2, lb/hr	461.9	464.7	474.7
Mercury, ppm dry (Average Units 7–9)	0.062	0.062	0.062

RESULTS AND DISCUSSION

Baseline Tests

Baseline tests were performed during the week of February 13, 2006. Baseline testing was done without PAC injection. Efforts during this week included sampling of coal and ash, monitoring the CEMs and plant data, and performing mercury, halogen, and particulate testing on the flue gas into and out of the baghouse.

A total of 24 test points were sampled using six ports at the baghouse common inlet and outlet test locations. The particulate sample trains met all specifications required by Method 5, 40CFR60. Table 3 shows the results of this study and the significant decrease in outlet emissions across the baghouse. It is important to note that these measurements were not made at the design inlet loading, which includes the combination of ESP outlet emissions and carbon injection.

Table 3. Particulate Removal across the Baghouse.

Run #	Inlet (lb/hr)	Outlet (lb/hr)
1	84.8	4.18*
2	104.4	0.37
3	141.1	0.56
Average	110.1	0.46

*Not included in average due to inconsistency

A total of 24 test points were sampled using six ports at the baghouse common inlet and outlet test locations. The speciated mercury sample trains met all specifications required by the Ontario Hydro method. Table 4 shows a comparison of the average inlet and outlet measurements from 10 a.m. through 4 p.m. using the Thermo CEM and the Ontario Hydro Method. There was a 0.6% difference between inlet and outlet based on the CEM, but 9% when using the Ontario Hydro Method. The CEM and the Ontario Hydro results differed by 12% and 4.6%, which is well within the 20% agreement required by EPA to pass the Relative Accuracy Test Audit (RATA) for mercury.

Table 4. Comparison of Thermo CEM and Ontario Hydro Data.

Test Method	Inlet Average ($\mu g/sm^3$)	Outlet Average ($\mu g/sm^3$)	Differential (%)
Thermo CEM	4.99	4.96	**0.6%**
Ontario Hydro	5.67	5.20	**9.0%**
Differential (CEM & OH)	**12%**	**4.6%**	

Based on the Ontario Hydro data, the elemental mercury at the inlet was 91% of the total and oxidized was the balance, with just a trace of the mercury particle-bound. At the outlet, the elemental portion was 88%, with the remainder in the oxidized form.

Figure 2 shows inlet and outlet mercury concentrations, flange-to-flange pressure drop, and inlet temperature. There was some drift on the outlet CEM because the calibration routine was not programmed properly. When this was corrected and the instrument began undergoing daily calibrations, the mercury levels returned to the expected values.

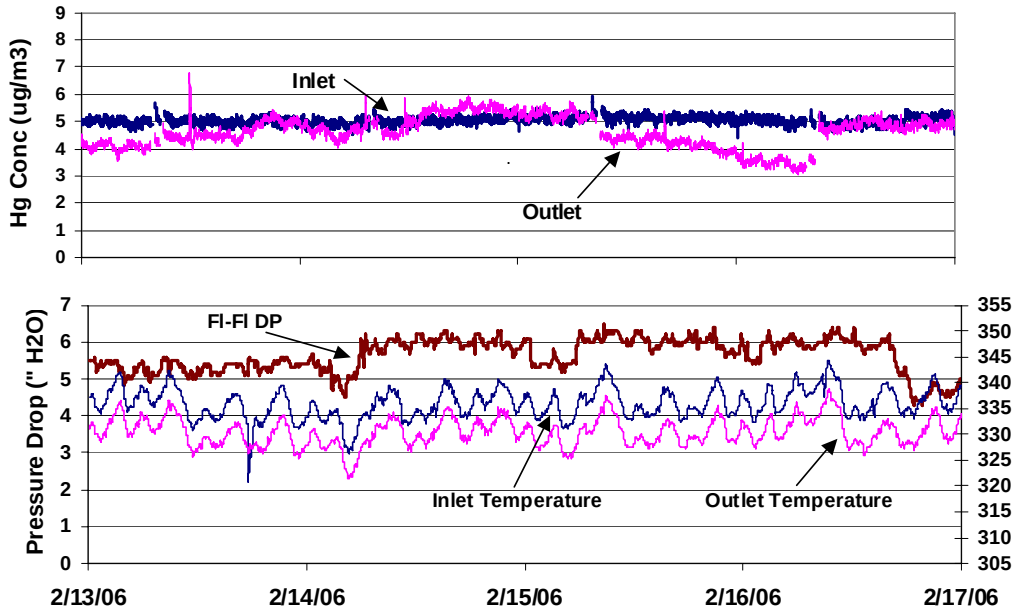

Figure 2. Baseline Inlet and Outlet Mercury Concentrations and Baghouse Pressure and Temperature.

Parametric Testing

The overall goal of these tests was to establish a correlation between injection of NORIT Americas DARCO® Hg activated carbon and mercury removal. Secondary goals included understanding the variables that impact mercury removal performance and to document any changes in baghouse performance.

On February 20, PAC injection was set at 0.5 lb/MMacf. At this condition, outlet mercury cycled between about 2.5 and 4.8 μg/m^3; these changes can be seen in Figure 3. After considering several variables that could affect outlet mercury concentration, including flue gas temperature, flue gas flow, boiler load, pressure drop, pulse cleaning, carbon feed, and hopper ash pulling, it became apparent that outlet mercury concentration was mainly varying with inlet flue gas temperature.

On February 23, the injection concentration was increased to 1.0 lb/MMacf. Average removal efficiency (RE) was nominally 73%, but varied between 69 and 80%. When injection concentration was increased, a slight increase in fl-fl pressure drop was also seen. On February 25, the injection concentration was increased to 1.5 lb/MMacf. Average RE was nominally 80%, but varied between 70 and 85%. On February 27, the injection concentration was increased to 2.0 lb/MMacf. The average RE was nominally 90%, but varied between 80 and 95%.

The relationship between mercury removal and inlet temperature during testing at 1 lb/MMacf can be seen in Figure 4. The cycling pattern of inlet temperature and the similar pattern for outlet mercury concentration are illustrated in Figure 5.

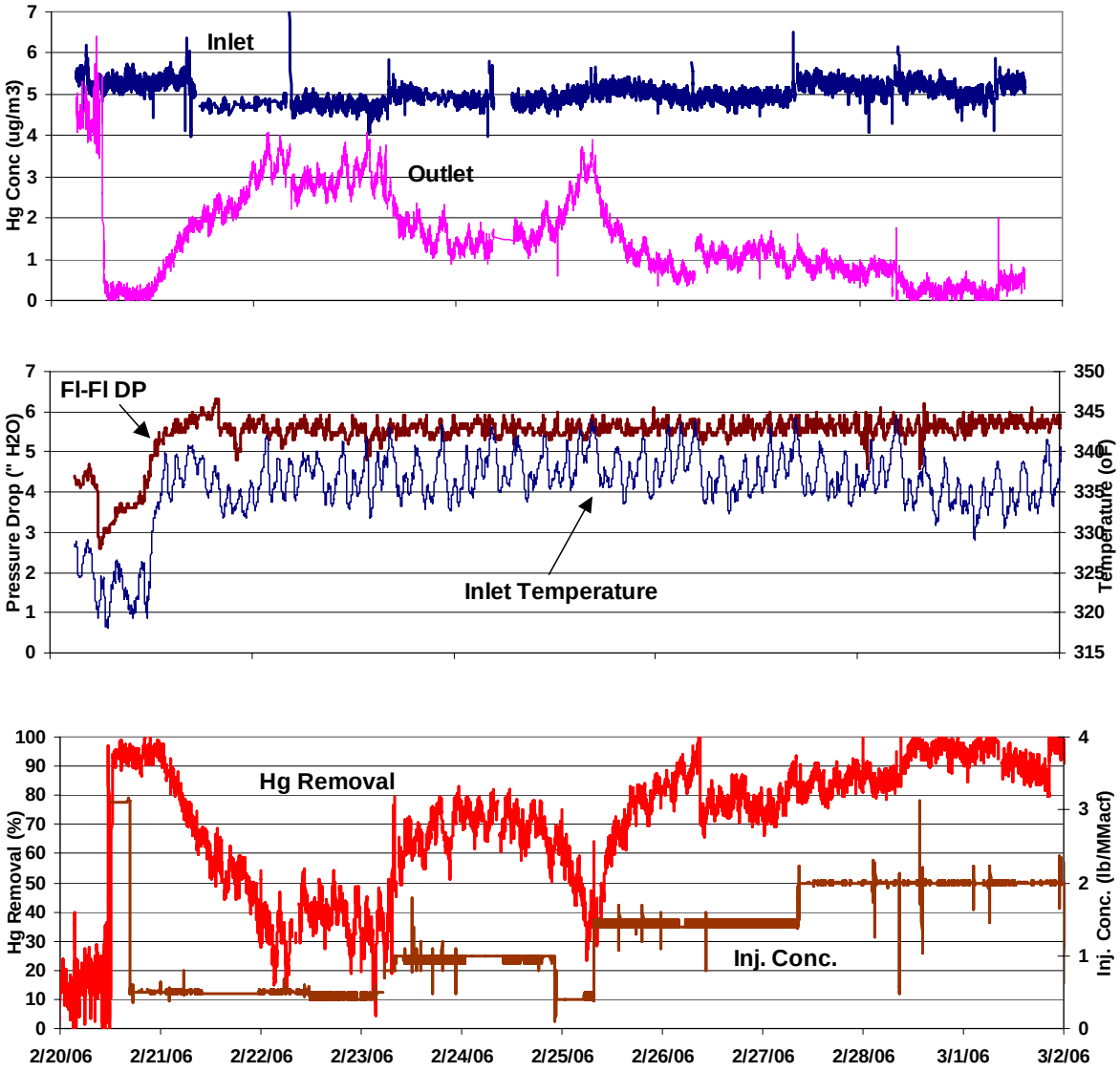

Figure 3. Inlet and Outlet Mercury Concentrations, Carbon Injection Concentration, Baghouse Pressure Drop, Inlet Temperature and Removal; February 20–March 1, 2006.

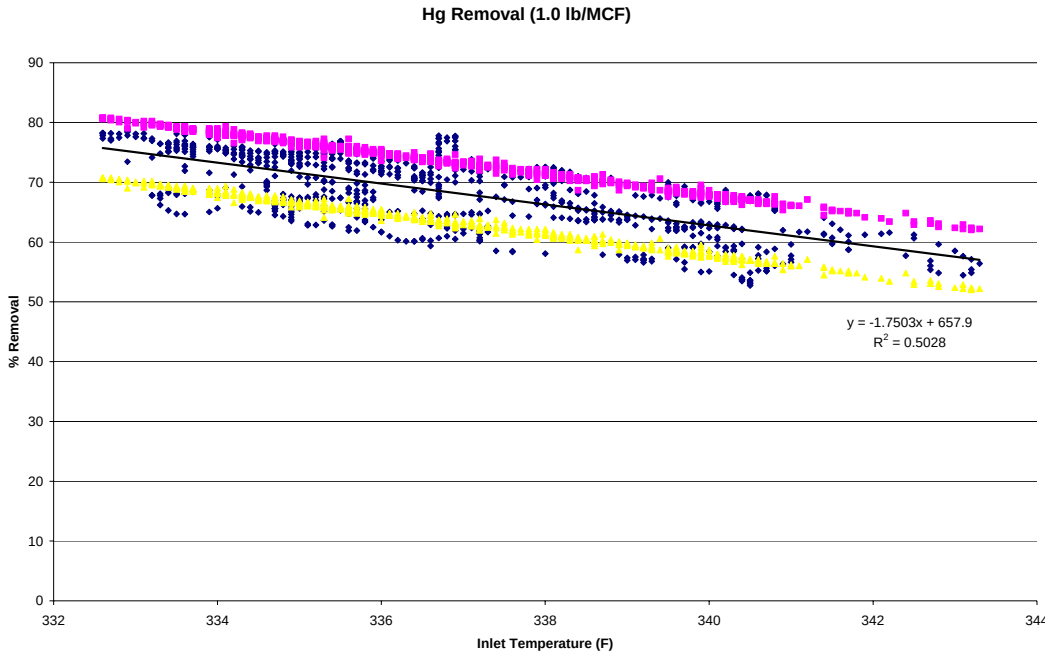

Figure 4. Linear Regression showing Relationship between Inlet Temperature and Mercury Removal Efficiency and +/- 5 % band.

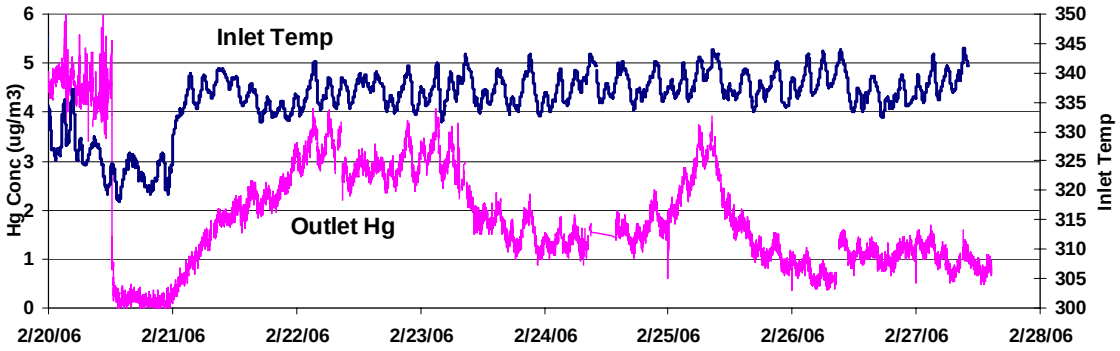

Figure 5. Inlet Temperature and Outlet Mercury Concentration.

The obvious and instantaneous response in outlet mercury concentration to changes in inlet temperature was surprising, especially in the magnitude of the change—a 10°F increase in temperature appears to result in up to a 1 $\mu g/m^3$ increase in mercury. We do know that this temperature range, 333–350°F, is where DARCO® Hg begins to lose its ability to adsorb mercury, so it is possible that we are just seeing the sensitivity in performance as temperature increases. Another factor is that as temperatures increase, mercury desorbs from the sorbent (activated carbon or ash) until a new equilibrium is reached. We believe we saw this during the shakedown period when outlet mercury was higher than inlet mercury after carbon injection was stopped. The overall removal efficiencies from the parametric tests can be seen in Figure 6.

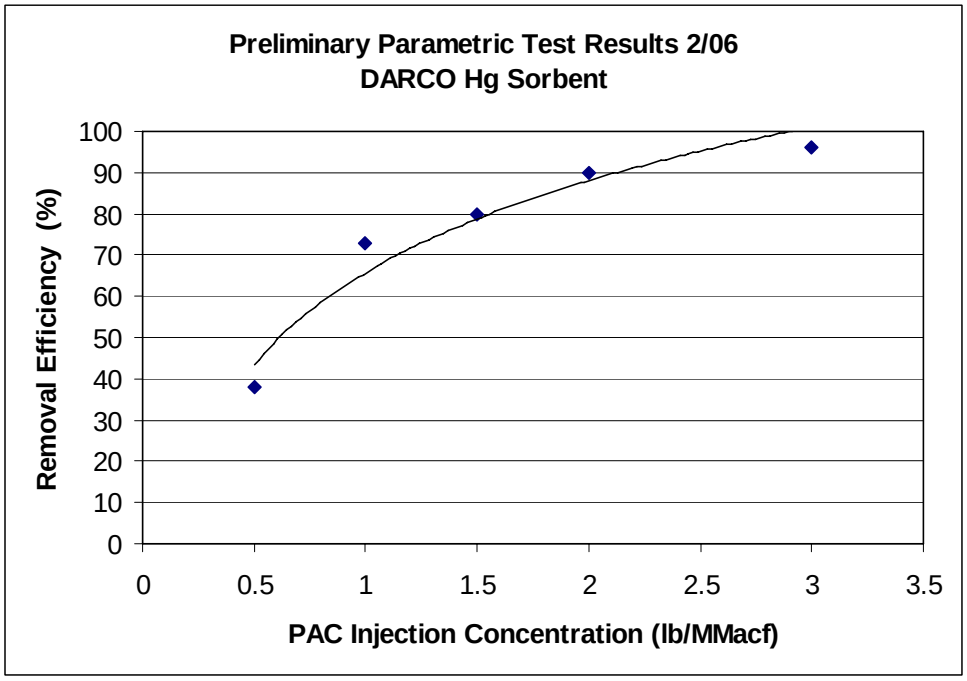

Figure 6. Mercury Removal Results from Parametric Testing; February–March, 2006.

Overheating of PAC/Ash in Baghouse Hoppers

After several weeks of parametric testing, hot, glowing embers were found in one hopper while operators were working to unplug and evacuate it. This compartment was isolated and the baghouse remained in service. All of the compartments were then checked and embers were found in all of the hoppers. The compartments were isolated, PAC injection was discontinued, and the baghouse put into bypass mode. The hot PAC/ash in each hopper was cooled and removed.

Loss on Ignition (LOI) was measured on select samples and values ranged from 15 to 35%. Thermogravimetric tests performed on the PAC and PAC/ash mixture showed a heat of combustion of around 850ºF, although smoldering of the PAC occurred at around 780ºF. An investigation of system operation and the ductwork showed no evidence that a burning substance had passed into the TOXECON™ baghouse and ignited the mixture.

Heaters are used on the hoppers in this baghouse and specifications showed that they could reach temperatures up to 800°F. At the time of the incident they were set to maintain an average temperature of 290°F. After all of the hoppers were emptied, thermocouples were placed on the hopper walls and the maximum wall temperature measured at the original setting was 407°F.

We Energies and ADA-ES are conducting testing to determine the cause(s) of overheating of the ash mixture in the hoppers. Testing includes analysis of the PAC/ash mixture and PAC for ignition properties. All tests to date confirm that the ignition temperature of PAC or of the PAC/ash mixture is around 850°F.

Literature searches revealed a model to predict auto-ignition of combustible materials called the Frank-Kamenetskii Model. This model predicts that spontaneous combustion can result from internal heating of a combustible solid if the solid is sufficiently porous to allow oxygen (air) to permeate it and if it produces heat faster than it can be liberated, which can happen with a highly insulating material. This phenomenon is normally associated with relatively large mass of material (small surface to volume ratio). The model describes a relation between the radius of a specimen and the self-ignition temperature in a defined geometry.

Laboratory oven tests were conducted on different size square containers filled with PAC/ash mixtures from the hoppers at PIPP. Thermocouples were placed in the oven and inserted into the bed of material at different levels to track temperature profiles over time. Temperature profiles from testing at 340°F and 430°F on a six-inch bed loaded with a PAC/ash material with an LOI of 26% are shown in Figure 7. These tests confirmed that at 430°F, sufficient heat was generated to increase the temperature of the mixture to ignition temperatures. Tests are ongoing to determine the effect of LOI, process temperature, bed size, and carbon type on auto-ignition temperatures.

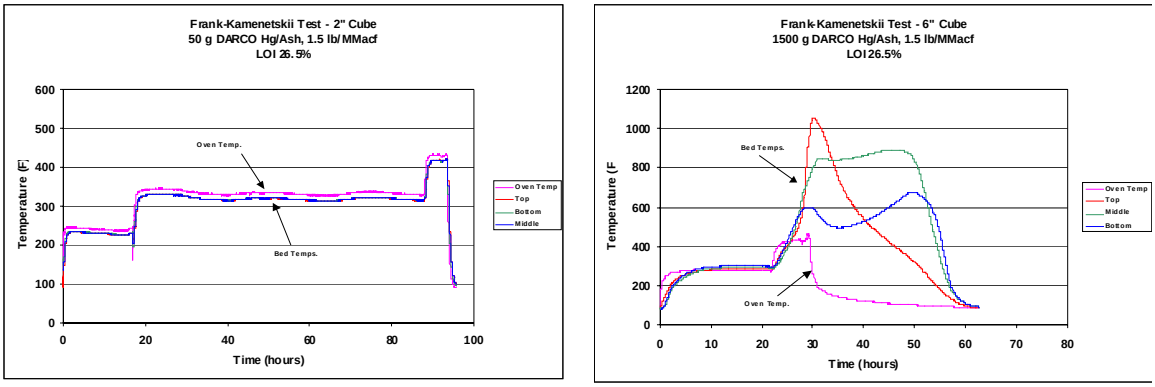

Figure 7. Temperature Profiles for Two Different Size Beds of PAC/Ash Mixture Placed in a Temperature-Controlled Environment.

Working with industry, the following preliminary design considerations and procedures are recommended to minimize the risk overheating of high carbon ash in hoppers:

1. Eliminate the use of hopper heaters.
2. If using hopper heaters, change the hopper heater control from an on-off mode to a more tightly constrained temperature band. This should result in a lower peak temperature output of the heater. Also, consider only using hopper heaters during start-up and shut-down.
3. Add or increase temperature monitoring in the hopper to include temperature sensors inside the hopper. This will help with early indication of unusual temperature increases.
4. Consider hopper design issues to ensure proper flowability of the collected material, especially with a high PAC-to-ash ratio.
5. Select a means of fluidization other than vibrators that does not promote packing of the material. Current options that are in operating systems throughout the utility

industry and other industrial sites are fluidization using a gas (air) or sonic horns. Further testing should be conducted to determine the effectiveness of vibrators for TOXECON™ systems.

6. Employ a hopper evacuation schedule that frequently removes hopper materials from the hoppers, preventing material build-up.
7. Install a hopper level detector system and ensure its reliable operation.

CONCLUSIONS

In collaboration with DOE in a Clean Coal Program, We Energies and team members successfully completed the design, construction, installation, and start-up of the first commercial mercury control system, EPRI's TOXECON™ process, on a coal-fired utility power plant. The new air pollution control system became commercially operational in late January 2006.

Initial parametric results with PAC injection indicated the mercury removal efficiencies were at the project stated goals of 90% mercury removal rates. After several weeks of continued PAC injection, balance-of-plant issues related to high carbon ash burning in the hoppers forced a delay in the testing. These balance-of-plant issues are exactly why DOE and industry team together to demonstrate new technologies. These alliances reduce financial and reliability risks to industry, while supporting the advancement of innovative, cost-effective new technologies. We Energies, DOE, and team members have identified the cause of burning PAC/ash in the hoppers and, working with industry, have developed preliminary guidelines for the safe operation of hoppers with high carbon ash, and continue to evaluate and gain experience in the operation of a TOXECON™ system. Parametric and long-term testing will continue through the end of 2006.

ACKNOWLEDGMENT

This paper is based upon work supported by the Department of Energy under DOE Cooperative Agreement No. DE-FC26-04NT41766.

DISCLAIMER